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Note to the Reader:

The second draft is a draft commentary of the Science Advisory Board (SAB). The draft is still undergoing final internal SAB review, and may not yet represent the consensus position of the Subcommittee involved in the review. Once approved by the Subcommittee, Environmental Engineering Committee and Executive Committee, the report will be transmitted to the EPA Administrator and will become available to the interested public as a final report.

This early draft has been released for general information to the public and to EPA staff. This is consistent with the SAB policy of releasing draft materials when the Subcommittee involved is comfortable that the document is sufficiently complete to provide useful information to the reader. The reader should remember that this is an unapproved working draft and that the document should not be used to represent official EPA or SAB views or advice. Draft documents at this stage of the process often undergo significant revisions before the final version is approved and published.

This version of the draft commentary will be discussed at the Subcommittee's April 18 conference call meeting as announced in the Federal Register February 15, 2001 (Volume 66, Number 32, Page 10496-10498). The Subcommittee welcomes comment from the Agency and the public on this draft and the next. Although, the SAB is not obligated to address the responses which it receives, it will make the comments part of the record. Comments on this draft will be accepted through April 18. A third draft will be issued about April 12 for discussion by the Subcommittee at it's April 18 conference call meeting. Comments on the following questions would be useful.

1. Are their any major points missing from this commentary?
2. Are any statements or responses made in the draft unclear?
3. Are there any technical errors?

For further information or to respond to the questions above, please contact:

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Commentary on Industrial Ecology
Draft 2, April 15 2001 (From V.Thomas)

1. Introduction

Over the past several years, there has been growing interest in the development of systems approaches to environmental management. These approaches acknowledge the interconnected nature of technological and environmental systems, and emphasize the potential for development of improved, environmentally benign technological systems. Recent reports from the SAB, including "Integrated Environmental Decisionmaking" and the EEC Commentary, "Overcoming Barriers to Waste Utilization," indicate increasing interest within SAB in this type of approach (EPA/SAB 2000). A number of environmental policy initiatives, in the US and especially in Europe and Japan, reflect this approach.

Paralleling these policy developments has been the development of the applied science of industrial ecology. It systematically examines local, regional, and global materials and energy uses and flows in products, processes, and industrial sectors and economies. It focuses on reducing adverse consequences throughout the life cycle of goods and services, from extraction of raw materials, to production, to use of those goods and services, and to the management of the resulting wastes, with the ultimate goal of advancing toward a desirable and sustainable society.

Industrial ecology emphasizes integrated systems thinking. The interactions between human and industrial activities and environmental impacts are seen as comprising a complex system, i.e. one in which there are several interacting components, whose combined interactions are often nonlinear, and for which solutions to defined problems require expertise from many disciplines. The systems perspective is frequently, but not exclusively, realized through use of materials balances or a life cycle approach. The emphasis is on long-term, strategic environmental management.

Industrial Ecology draws on and extends a variety of related approaches including life-cycle assessment, design for environment, materials flow analysis, pollution prevention, and eco-industrial parks.

Diagram(s) From The Published Literature

2. International Policy Developments

Developments in environmental policy around the world, as well as globalization, encourage attention to industrial ecology. These developments, especially those that encourage demand for and development of greener products, pose both opportunities for and challenges to American policy. They challenge US policy both because there is the possibility of inconsistent regulatory obligations across national borders and because the analytical and policy framework is somewhat different from the traditional US approach. They provide an opportunity for US policy because they present a portfolio of strategies and experiences from which the EPA can draw in its efforts to protect environmental quality in a cost-effective manner.

Historically, U.S. environmental regulations on industry have emphasized control of point sources, especially the gaseous, liquid, and solid emissions from manufacturing plants. Consequently, research has focused on emissions from industrial facilities.

In Europe, environmental policies increasingly address the overall environmental impacts of a product over its entire life cycle (raw materials extraction, product manufacturing, product use, and disposal or recycling). One example is the European Union's proposed Integrated Product Policy (IPP), which seeks to stimulate demand for greener products and to promote greener design and production ("Green Paper," 2001).

In Japan, the emerging emphasis is on the environmental design of products, driven both by concern over scarce resources and on development of the international market share of their products. Policies emphasize extensive recycling of products and product environmental attributes such as energy efficiency and use of non-toxic materials.

In response, global industrial firms, which participate in commerce in the US, Europe, and Japan, are beginning to apply these concepts to their products, manufacturing processes, and environmental programs.

These developments signal an international shift in emphasis from managing individual manufacturing waste streams to managing the overall environmental impacts of a product over its life cycle. The growing diversity of environmental policies for products could raise trade issues; on-going activities in the European Union and other countries could place the U.S. in a reactive mode.

3. RESEARCH NEEDS

Industrial ecology has significant potential. But there is much to be done to develop the scientific foundation of this emerging field. Industrial ecology research needs to develop a quantitative theoretical foundation that is tested and validated through data and experiments. The development of such a foundation will provide a basis for evaluating the generalizability as well as the limitations of the key concepts and assumptions of the field. The overarching needs are forexamination of the substantive premises of the field, and for critical assessment of the tools, metrics and assumptions that are rapidly emerging in industrial ecology.

Examining Substantive Premises

Industrial ecology proposes a number of intriguing substantive premises about the manner in which the economy and the biophysical environment can and do interact. These include:

a) *dematerialization* - Dematerialization is defined as a decline over time in the weight of materials required to serve economic functions, measured either per person or per unit of economic activity. Although the declining importance of materials in the economy was first noted in 1966 (Radcliffe, 1966), fundamental understanding of the trends and their environmental implications is lacking. Knowledge of the extent and mechanisms behind the patterns of material use are limited largely to individual materials or specific industries.(Cleveland and Ruth, 1998).

b) *loop closing* - industrial ecology looks to the cycling of resources through by-product exchange, materials recycling, product re-use, increased product durability and related endeavors as way to reduce environmental burdens. These are familiar topics for the EPA, but industrial ecology treats them in an integrated manner that is more ambitious and systematic. Research is needed to understand both the limitations and the potential benefits of loop closing throughout the economy.

c) *moving from products to services* - the notion that people seek not physical products, but rather the services provided by those products holds potential for innovative environmental strategies and considerable environmental gain. Product-to-service strategies need further conceptual analysis and systematic empirical testing.

d) *looking to firms to take a proactive role in environmental improvement* -Industrial ecology looks for firms to take a leading role in environmental management and policy. There are two dimensions to this premise:

(i) optimism that appropriate circumstances can be found or crafted to facilitate voluntary approaches to environmental improvement, and

(ii) reliance on firms as the locus of technological expertise which in turn is seen as crucial to strategies emphasizing design for environment (DfE).

It is often argued that cooperative approaches are more cost effective, more conducive to innovation, and better able to promote fundamental attitudinal change than traditional "command and control" regulation. Better understanding is needed of both the limitations of the industrial role and circumstances which can encourage industry to be environmentally proactive. There is a need for greater attention to program evaluation, and more rigorous research to examine the effectiveness of the new policy instruments and to compare them with traditional regulatory and market-based incentives (O'Rourke et al., 1996; Harrison, 1998).

e) Resource limitations: Minimizing the reliance on external inputs is an underlying premise of much research in industrial ecology (Graedel and Allenby, 1995, Lifset and Graedel, 2000). Over the past several decades the extent to which resource limitations will present environmental or economic constraints has been a contentious issue (Tierney, 1990; Holdren et al., 1980). A fundamental understanding of these issues has yet to emerge.

Significant advances on these questions are likely to require new theoretical developments , quantitative models, field-scale and large-scale experiments, and empirical research.

Critical Assessment of Tools and Metrics

Industrial ecology has generated and uses an ensemble of tools and metrics for detailed analysis and for practical decision-making. These tools and metrics need critical evaluation and peer review.

Tools

Tools to assist in environmental evaluation at a variety of scales, but especially for product design, are proliferating rapidly (de Caluwe, 1997)Even where regulatory obligations are not involved, the EPA has an institutional interest in promoting the use of tools that are analytically sound. These tools are often complex, opaque in their technical assumptions, and use data that are difficult to verify.

For example, life-cycle inventory databases have been developed to quantify material and energy flows of industrial products during extraction and processing of raw materials; manufacturing of products; product use; and disposal or recycling (http://www.epa.gov/ORD/NRMRL/lcaccess/)Currently available databases have significant limitations. Most are proprietary and have not been peer-reviewed or validated. They are not standardized; and their variability and uncertainty are unknown.

Technical review of these tools could provide users with increased confidence that actions based on the tools would indeed lead to environmental improvements. This research could include both conventional peer review that examined the various aspects of the tools, and development of standardized "test-beds" (data sets or protocols) that would allow results of different tools to be compared.

Metrics

Because industrial ecology emphasizes a systems approach, use of aggregated metrics is common. Examples of aggregated metrics include Global Warming Potential, a measure of a molecule's contribution to global warming, or Swiss eco-points, a measure of overall environmental impact, or human toxicity potential, a measure of the toxicity of chemical compounds over a range of human health endpoints. Many industrial companies have been trying to balance triple bottom lines; business; environmental; and societal. Aggregation of these bottom lines in a single metric remains a major hurdle.

At issue is how commensurate these metrics are, what uncertainties, variabilities, and social and economic values are embodied in them, and how they may obscure information or reduce specificity. For example, the toxicity of a chemical is a function of the medium of exposure, the duration of exposure, the state of the receptor (condition, characteristics and activity level), the route of exposure and the chemical/physical state of the pollutant. Application of poorly conceived metrics may lead to perverse outcomes. Hence there is a need for deeper understanding of how metrics are developed, of the impacts of uncertainty and variability, and of the limitations and benefits of their application.

Simplifying Assumptions

Industrial ecology has generated an ensemble of simplifying assumptions used in calculations and analysis. These simplifying assumptions range from the informal (e.g., streamlined life cycle assessment captures 80% of the opportunities for environmental improvement that a more elaborate analysis would generate (ref?), or mass is a reasonable proxy for environmental damage in materials flow analysis (ref?)) to somewhat more analytical (e.g., boundaries for life cycle assessment can approximated by the one-step-back or 5% rules) (ref?). Quantitative evaluation of claims that underlie these assumptions could define both when such assumptions provide reliable guidance and the type and extent of uncertainty that arises when they are used. Examples of this sort of work include quantitative comparison of the uncertainty that arises when input-output based LCA is used in lieu of "traditional" process-based LCA (Lenzen 2001) or the examination of the correlations between product attributes, environmental releases and environmental impacts (Inês 2001).

4. FINAL REMARKS

Industrial ecology offers the potential to achieve key environmental policy goals in a cost-effective manner. It can complement and enhance the single-pollutant risk-based framework of traditional environmental policy. The US EPA has initiated a number of activities related to Industrial Ecology (EPA, 2001). These efforts provide a good foundation for future development of both research and policy. Development and implementation of industrial ecology will require attention to its diffusion and adoption throughout EPA, as well as in the broader scientific, educational, and policy communities (SAB 2000).

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